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METROPOLITAN WATER WORKS

By DEXTER BRACKETT

A Paper Presented at the Twenty-Sixth Annual Convention of the

AMERICAN WATER WORKS ASSOCIATION.

WACHUSETT DAM, SHOWING RAILROAD BRIDGE OVER WASTE CHANNEL.

METROPOLITAN WATER WORKS.

By Dexter Brackett.

In the year 1892 the City of Boston had nearly reached the capacity of its sources of water supply, and there were several other metropolitan municipalities whose sources of supply were either inadequate in quantity or inferior in quality. It was evident that for the future supply of the Boston Metropolitan District a comprehensive scheme was demanded, and as such a scheme must necessarily affect not only the different municipalities to be supplied but also the towns in the more remote districts from which the water would be obtained, it appeared advisable to have the investigation of the question made under the supervision of the State.

In 1893 a bill providing for the appointment of a commission to investigate the question was introduced in the Legislature by one of the representatives of the City of Boston, which resulted in the passage of an Act approved June 9, 1893, directing the State Board of Health to investigate the subject and report on or before the first Wednesday in January, in the year 1895.

After a very careful and thorough investigation of the possible sources of supply, the more important of which were Lake Winnipiseogee, in New Hampshire, the Merrimack River and the South Branch of the Nashua River, the State Board of Health, in February, 1895, presented its report recommending the taking of the water of the South Branch of the Nashua River at a point above the Lancaster Mills in the town of Clinton, and the construction of works for utilizing this source in conjunction with the sources then used by the City of Boston.

The Metropolitan Water Act, Chapter 488 of the Acts of the year 1895, approved June 5, 1895, provided that the Governor should appoint three water commissioners who should constitute the Metropolitan Water Board, and that this Board should construct, maintain and operate a system of water

works substantially as recommended by the State Board of Health.

The Board was thus directed by the Act to take for the Metropolitan Water Works the waters of the South Branch of the Nashua River, at a point in the town of Clinton within the Commonwealth and about 35 miles westward from Boston; to construct for the storage of the waters a dam and reservoir; to build an aqueduct from the dam at Clinton, about 12 miles long, to the Sudbury Reservoir situated in the town of Southborough and the city of Marlborough, which had already been begun by the City of Boston; to complete this reservoir and connect it with the Sudbury Aqueduct of the City of Boston; to take from the City of Boston the Cochituate, Sudbury and Mystic systems, which were its sources of water supply, and the Chestnut Hill Reservoir and pumping station; also to take Spot Pond, which was then used as a source of water supply by the cities of Malden and Medford and the town of Melrose; and to lay the main pipes required to supply at some proper point each of the several cities and towns embraced within the water district.

The Board was given broad powers, not only for the construction of the works, but also for the taking of property, for the changing of highways and railroads, and for the conduct of such operations as should be deemed necessary for protecting and preserving the purity of the water.

No estimate of the total expenditure involved in the scheme adopted was made, but it was provided that the Commonwealth should issue bonds to an amount not exceeding $27,000,000, the proceeds of which should be applied to meet the expenditures occasioned by the various operations of the Board. For the payment of the loan at its maturity a sinking fund was to be established, and assessments were required to be made upon the various municipalities included within the district sufficient to meet the cost of maintenance and the interest on the indebtedness, and for contributions to a sinking fund sufficient to secure the payment of the indebtedness at its maturity. Provision was made by the Act not only for the payment for all lands and other property taken for the works, and for the loss of water and water power occasioned by the diversion of

the waters of the river, but also for the payment of indirect damages occasioned by the depreciation of the property affected by the operations of the Board, but which was not taken. Annual payments were directed to be made to the towns of Boylston and West Boylston, in which the larger part of the lands were taken for the new reservoir, to compensate them for the loss of taxes and other damages suffered by them in their corporate capacity; and compensation was afforded to individuals for injury occasioned to established business and on account of the loss of employment.

The Metropolitan Water District, as established under the Act, consisted of the cities of Boston, Chelsea, Everett, Malden, Medford, Newton, Somerville and the towns of Belmont, Hyde Park, Melrose, Revere, Watertown and Winthrop. The Act further provided that any one of the other cities and towns, any part of which is within a radius of ten miles of the State House, should, on application, be admitted into the District, upon payment of such sum of money as should be determined by the Board. Under this provision the city of Quincy and the towns of Nahant, Arlington, Stoneham, Lexington and Milton have since been admitted into the District, and under authority given by the original and subsequent acts, water is also supplied to the town of Swampscott and to a small portion of the town of Saugus, both of which are without the limits of the District.

The nineteen municipalities within the District as now established had, in 1905, a population, according to the census of that year, of 946,300, as appears by the following table:

City or Town.	Population, Census of 1905.
Boston	595,380
Somerville	69,272
Malden	38,037
Chelsea	37,289
Newton	36,827
Everett	29,111
Quincy	28,076
Medford	19,686
Hyde Park	14,510
Melrose	14,295
Revere	12,659
Watertown	11,258
Arlington	9,668
Milton	7,054
Winthrop	7,034
Stoneham	6,332
Lexington	4,530
Belmont	4,360
Nahant	922
Total population of Metropolitan Water District	946,300
Swampscott	5,141
Part of Saugus	200

Water is supplied to Swampscott and a small portion of the town of Saugus outside the limits of the Metropolitan Water District. The city of Newton and the town of Hyde Park are supplied from local sources, so that the population supplied from the Metropolitan Works in 1905 was 902,090.

The Metropolitan Water Board, as first constituted, consisted of Henry H. Sprague of Boston, chairman; Wilmot R. Evans of Everett, and John R. Freeman of Winchester. Mr. Freeman, on account of removal from the Commonwealth, resigned his membership on April 15, 1896, and Henry P. Walcott, M. D., of Cambridge, the chairman of the State Board of

Health, was appointed in his stead and began service upon the Board on April 16, 1896. On March 20, 1901, the Metropolitan Water Board and the Board of Metropolitan Sewerage Commissioners were abolished and a new Board, known as the Metropolitan Water and Sewerage Board, was created and given all the powers and duties of the abolished Boards. This Board, composed of Henry H. Sprague and Henry P. Walcott from the Metropolitan Water Board, and James A. Bailey, Jr., who had been the chairman of the Sewerage Commission, has remained unchanged in membership. William N. Davenport has been secretary of the Board since its organization. Frederic P. Stearns, as chief engineer of the State Board of Health, had charge of the investigations made in 1893 and 1894 previous to the passage of the Act, and as chief engineer of the Water Board and of the Water and Sewerage Board he has had charge of both the designing and construction of all the water works built since 1895.

In order to obtain, as quickly as possible, an addition to the water supply, the first work undertaken was the building of an aqueduct for conveying water from the Nashua River to the Sudbury Reservoir, the completion of this reservoir which had been commenced by the City of Boston, the increase of pumping facilities, and the laying of main pipes from the Chestnut Hill pumping station to connect with Spot Pond and the various cities and towns to be supplied with water.

The first contract entered into by the Board, which was for cast-iron pipes, was made December 27, 1895. The first contract for the Wachusett Aqueduct was made February 14, 1896, and on March 7, 1898, the aqueduct was substantially completed, and water from the Nashua River was diverted through the aqueduct into the Sudbury Reservoir, which, although not finished until December, 1898, was at that time so far completed as to be used to a limited extent.

On January 1, 1898, formal possession was taken of the works of the City of Boston, and the use of water from the Mystic supply, from which, up to that time, about 12,500,000 gallons per day had been supplied to Somerville, Chelsea, Everett and portions of Boston, was discontinued. On December 11, 1898, a new 30-million gallon pumping engine was first operated at the high-service station at Chestnut Hill.

During the year 1899 the Fells Reservoir, used for the supply of the higher portions of the northern part of the District, was completed and placed in service, and the work of improving Spot Pond was commenced. During the year 1900 the low-service pumping station at Chestnut Hill and the high-service pumping station at Spot Pond were completed and the pumping engines placed in service. The work of raising and improving Spot Pond was also completed during that year.

The first contract for the removal of soil from the Wachusett Reservoir was made July 14, 1897, and work on the final contract was completed in November, 1905. In 1897 a temporary dam was constructed across the Nashua River preliminary to the construction of the main dam, also for the purpose of diverting the water of the river into the Wachusett Aqueduct. The work of excavating for the main dam was commenced in July, 1900, by day labor. The contract for the dam was made October 1, 1900, and the dam was practically completed at the end of 1905. The construction of the Weston Aqueduct was begun May 22, 1901, and the aqueduct was completed and placed in service December 29, 1903.

Description of Works.

Water supplied by the Metropolitan Water Works is obtained from three sources, Lake Cochituate, the Sudbury River and the Nashua River. Lake Cochituate and the Sudbury River were acquired as sources of water supply by the City of Boston, the former in 1846 and the latter in 1872, and works for storing and conveying the water from these two sources were constructed by the City of Boston.

The construction of works for storing and conveying the water of the Nashua River was begun by the Metropolitan Water Board in 1895, and is now practically completed. Water was first drawn from this source on March 7, 1898. The Sudbury Reservoir of the Sudbury River supply was begun by the City of Boston and completed by the Metropolitan Water Board.

The works as at present constituted comprise the

Wachusett Reservoir on the Nashua River, capacity 63,000,000,000 gallons;

Eight storage reservoirs on the Sudbury River watershed, with a combined capacity of 13,616,100,000 gallons;

Lake Cochituate, capacity 2,242,400,000 gallons;

Wachusett Aqueduct for conveying water from the Wachusett Reservoir to the Sudbury Reservoir of the Sudbury supply, capacity 300,000,000 gallons in 24 hours;

Weston Aqueduct and Reservoir for conveying water from the Sudbury Reservoir to the Metropolitan District, capacity of aqueduct 300,000,000 gallons per day;

Sudbury River aqueduct for conveying water from the reservoirs on the Sudbury River to Chestnut Hill Reservoir, capacity 103,000,000 gallons per day;

Cochituate Aqueduct for conveying water from Lake Cochituate to the Chestnut Hill Reservoir, capacity 18,000,000 gallons per day;

Chestnut Hill Reservoir, which receives and stores water supplied through the Sudbury and Cochituate aqueducts, and from which water is pumped for supplying the Metropolitan District;

Five pumping stations located at Chestnut Hill Reservoir, Spot Pond, West Roxbury and Arlington, containing 13 pumping engines having an aggregate capacity of 204,500,000 gallons in 24 hours;

Six distributing reservoirs, of which Spot Pond is the largest, and two standpipes, located in the Metropolitan District, having a combined capacity of 1,881,230,000 gallons;

84.2 miles of pipes, ranging in size from 60 inches to 12 inches in diameter, through which water is delivered to a population of about 900,000 residing in eighteen cities and towns.

Wachusett Reservoir.

The Wachusett Reservoir is located in the towns of Clinton, Boylston and West Boylston, and is formed by a dam across the South Branch of the Nashua River located about half a mile above the settled portion of of the town of Clinton, and

by two earth dikes, one on either side of the valley a short distance above the main dam.

The river above the dam has a watershed of 118.32 square miles. The reservoir is 8.41 miles long, with a maximum width of 2 miles, an area of 4,195 acres, or 6.56 square miles, and a capacity of 63,068,000,000 gallons. The maximum depth of water is 129 feet; the average depth 46 feet.

In constructing the reservoir the soil was stripped from 3,943 acres of the submerged area to an average depth of one foot, the quantity removed being 6,900,000 cubic yards, and over about 150 acres where there were deep deposits of muck, gravel was spread to a depth of one foot. The plant used by the contractor in removing the soil included 27 miles of railroad track of 3-feet gage, 25 eight- to sixteen-ton locomotives, and 725 cars of from 1¾ to 3½ cubic yards capacity. The land required for the reservoir contained 6 large mills, 8 schoolhouses, 4 churches and about 360 dwelling houses occupied by 1,700 people.

In order to provide a new location for the Central Massachusetts Railroad, which ran for 6½ miles through the reservoir site, about 4½ miles of new railroad was built, the construction including a rock tunnel 1,110 feet long, a steel viaduct 917 feet long crossing the valley of the Nashua River, with a maximum height of 133 feet, and 1,500 linear feet of rock cut having a maximum depth of 56 feet.

The construction of the reservoir necessitated the discontinuance of 19¼ miles of roads and the construction of 11.8 miles of new roads, one of which crosses the reservoir on an embankment 700 feet long and from 50 to 70 feet in height.

The Wachusett Dam is a granite masonry structure comprising the main dam 944 feet long, including abutments at each end, crossing the valley of the river, with its top 20 feet above high-water level in the reservoir, and a waste weir 452 feet long, over which the flood waters can be discharged into a channel 1,150 feet long excavated in rock following the contour of the hillside to the river channel below the dam.

The main dam is composed of granite rubble masonry quarried about a mile from the dam, with facing, where exposed, of ashlar quarried in Chelmsford, Mass. The height of the

WACHUSETT RESERVOIR—ARCH BRIDGE AND HIGHWAY EMBANKMENT AT WEST BOYLSTON.

SITE OF WACHUSETT DAM—TEMPORARY DAM WITH WASTE-WAY AND CONDUIT CONNECTING WITH TUNNEL.

WACHUSETT DAM—EXCAVATION AT TIME OF BEGINNING MASONRY CONSTRUCTION.

WACHUSETT DAM AND TOWER AND GATE HOUSE.

top of the dam at the point of deepest excavation is 207 feet, and the maximum thickness is about 185 feet. The thickness of the dam 95 feet below high-water level in the reservoir is 81.5 feet, and under the projecting cornice at the top 22.5 feet. The northwesterly end of the dam terminates in a bastion in which, above high-water level, there is a room for the storage of flash boards for use on the waste weir. Beyond the bastion the waste weir extends for 452 feet, on which are cast-iron standards spaced 10 feet apart, containing grooves for flash boards and supporting a bridge.

Passing through the dam, embedded in the masonry, there are four 48-inch cast-iron pipes with their bottoms at elevation 284, above Boston City Base or 111 feet below high water in the reservoir. These pipes connect with circular vertical wells which extend to above high-water mark. Two wells are provided for each pipe, the up-stream one containing two 2½ feet x 6 feet sluice gates at levels 33.5 and 65.5 feet below high water, through which water can be admitted from the reservoir to the down-stream well, and thence into the pipe. Water is admitted to each of the up-stream wells through six ports in the masonry, each 8 feet high and 2.5 feet wide. On the down-stream side of the ports there are three pair of composition grooves in which can be placed screens and stop planks so arranged as to draw the water from the reservoir at any desired depth. The chamber containing the apparatus for operating the gates and screens is built in the dam above high water level and entirely below the top of the dam. The four lines of 48-inch pipes, after passing through the dam, enter the lower gate-chamber which is designed to receive machinery for utilizing the power of the water as it falls from the reservoir to the Wachusett Aqueduct, and also serves as a head-house for the aqueduct. This building contains valves for controlling the flow of water into the aqueduct or into pipes which discharge into a masonry pool 150 feet in diameter, from which it flows into the river channel.

On the north side of the valley, beginning about 1,500 feet above the dam and extending for two miles, and on the south side beginning 2,500 feet above the dam and extending for about half a mile, the elevation of the ground was

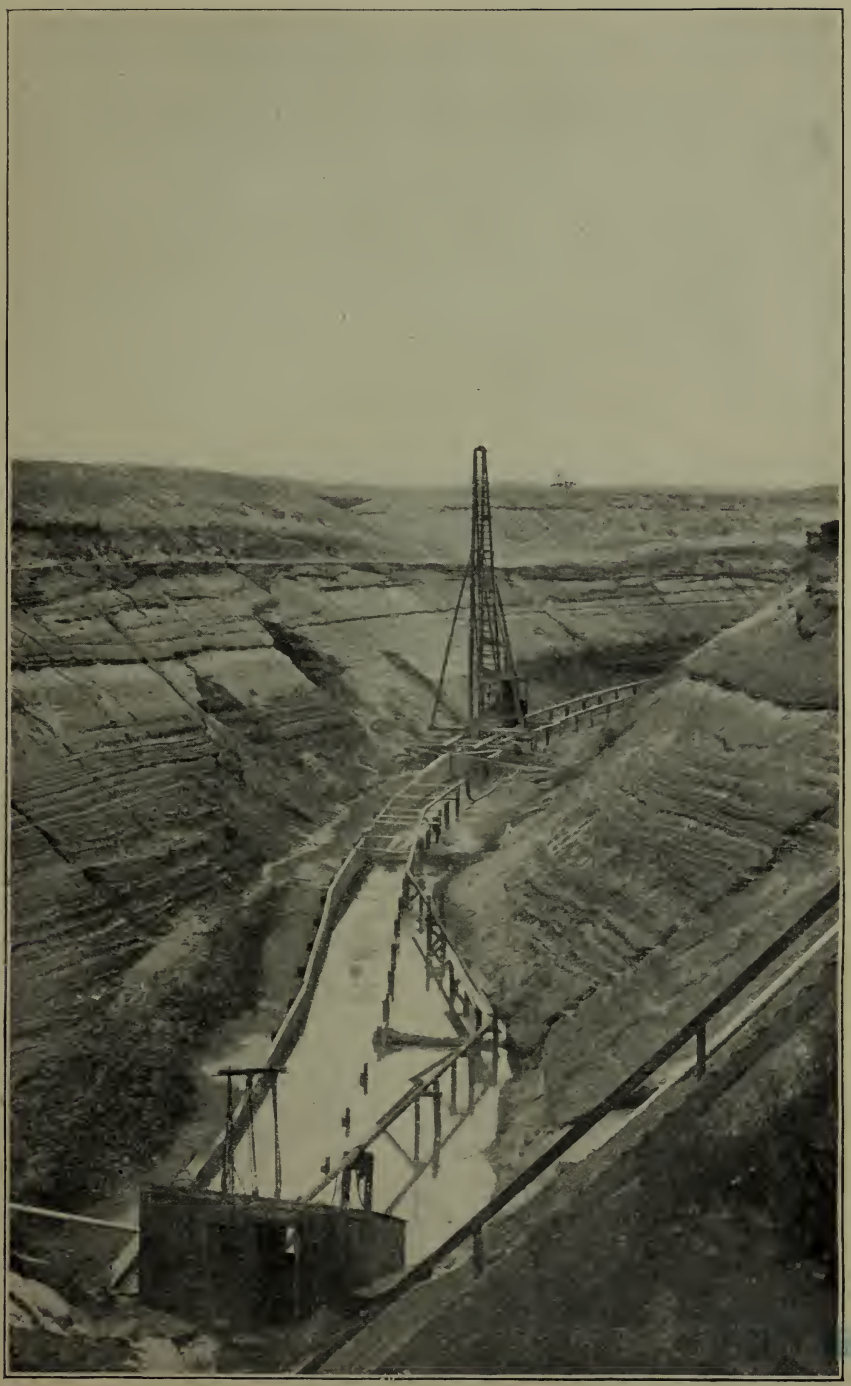
WACHUSETT DAM SHOWING RAILROAD VIADUCT AND WASTE CHANNEL.

WACHUSETT RESERVOIR—HIGHWAY BRIDGE OVER WASTE CHANNEL.

lower than the elevation of the water in the full reservoir. Overflow from the reservoir at these points is prevented by earth dikes composed of the soil removed from the bottom of the reservoir. The north dike is in two sections, respectively 4,300 and 6,700 feet long. Its maximum height above the original surface is 65 feet to full reservoir level, and 80 feet to the top of the embankment. The greatest width of the dike is 1930 feet, and it contains 5,861,814 cubic yards of earth, of which 4,955,936 cubic yards is soil removed from the reservoir. To secure water-tightness a cut-off trench, 9,505 feet long, 30 feet wide at the bottom, with slopes of one vertical to one horizontal, was dug parallel with and about 100 feet back from the reservoir side of the dike, through the gravel and coarse sand, to depths of from 30 to 60 feet, until rock or very fine sand nearly impervious to water was generally found. In the bottom of this trench, for a distance of 5,239 feet, sheet piling generally six inches in thickness was driven to a maximum depth of 52 feet below the bottom of the trench. The trench and the embankment above for a width of 100 feet was filled with soil from the reservoir, put in in six-inch layers, watered and rolled. Where the dike is exposed to the waves it is faced between elevation 382 and 400 with riprap of heavy stones about 12 feet in thickness. The south dike is about 2,800 feet long, with a maximum height of 30 feet below the full reservoir level. As in the north dike there is a cut-off trench carried down to rock or impervious material, filled with soil taken from the reservoir. The face of the dike is gravel protected, where exposed to the waves, by granite ripraps, about 12 feet thick.

Reservoirs on the Sudbury Supply.

The Sudbury River, above the point of diversion, has a drainage area of 75.2 square miles, on which eight storage reservoirs have been built by damming the river and its tributaries at various points.



WACHUSETT RESERVOIR—PORTION OF NORTH DYKE SHOWING MAIN CUTT-OFF TRENCH AND SHEET PILING.

WACHUSETT RESERVOIR—PORTION OF NORTH DIKE SHOWING MAIN CUT-OFF TRENCH PARTLY REFILLED WITH IMPERVIOUS SOIL.

The following reservoirs are located on this source:

	Area of water surface (acres).	Available capacity (million gallons).	Elevation above Boston City Base (feet).	Date when completed and filled.	Total height of dam (feet).	Maximum depth of water (feet).
Framingham Reservoir No. 1	143	287.5	169.27	Jan., 1879	22	16
Framingham Reservoir No. 2	134	599.9	177.12	Aug., 1879	26	20
Framingham Reservoir No. 3	253	1,183.5	186.50	Dec., 1878	29	24
Farm Pond	159	167.5	159.25		12	12
Ashland Reservoir	167	1,416.4	225.21	Apr., 1886	58	48
Hopkinton Reservoir	185	1,520.9	305.00	May, 1895	59	53
Whitehall Reservoir	601	1,256.9	337.91		13	18
Sudbury Reservoir	1,292	7,253.5	260.00	Apr., 1898	..	65
Total		13,616.1				

No attempt was made to remove the soil from Framingham reservoirs 1, 2 and 3 at the time of construction, but much of the organic matter was removed from Reservoirs 2 and 3 between the years 1882 and 1886, at a cost of about $200,000. The soil was removed from the bottom of the Ashland, Hopkinton and Sudbury reservoirs at the time of construction.

The dams of Framingham Reservoirs 1, 2 and 3 are each constructed with an earth embankment containing a center wall of rubble stone laid in cement mortar, with a waste overfall made of rubble masonry faced with cut granite. Adjacent to each overfall is a gate-chamber containing gates for controlling the water. The dams of Framingham Reservoirs 1 and 3 have a foundation of sand and gravel, while that of Framingham Reservoir No. 2 is ledge under the overfall and gate-chamber and sand or gravel for the remainder of its length. The gate-chambers of Framingham Reservoirs 2 and 3 are connected with the gate-chamber of Framingham Reservoir No. 1 by lines of 48-inch cast-iron pipe, one line from Reservoir No. 2 and two lines from Reservoir No. 3. Through these pipe lines water from these reservoirs can be delivered into the Sudbury River aqueduct without mingling with the water in Reservoir No. 1.

The dams of the Ashland and Hopkinton reservoirs consist of earth embankments 20 feet wide on top, containing a core wall of concrete masonry eight feet thick at the base and three feet at the top, extending to the bed rock, and carefully plastered on the water side with neat cement. The Ashland dam has an outside slope of 2½ to 1, covered with soil, an inner slope of 1½ to 1, covered with paving 15 inches thick, to a berm 6 feet wide 13 feet below the top of the dam, and a 1.65 to 1 slope, covered with riprap, below the berm. The Hopkinton dam has an outside slope of 2 to 1 from the top about half way down the slope, and 2½ to 1 below that point, and an inner slope of 2 to 1 with a berm 6 feet wide 13 feet below the top of the embankment. The inner slope is paved above the berm and riprapped below. At both the Hopkinton and Ashland dams a wasteway is placed at one end of the dam and the waste water is returned to the stream through a paved channel built in steps following the contour of the hillside.

The dam of the Sudbury Reservoir consists of an earth embankment with concrete masonry core wall extending to bed rock, with a granite masonry wasteway and gate-chamber situated near the middle of the structure. The dam is 1,865 feet long, including the wasteway 300 feet in length. The embankment is 14 feet wide at the top and has an outer slope of 2 to 1 from the top to a berm 8 feet wide 22 feet below, and 2½ to 1 below that point. The inner slope is paved and has a slope of 2 to 1 with a berm 6 feet wide 13 feet below the top of the dam.

Lake Cochituate.

Lake Cochituate, situated about 18 miles west of Boston, is a natural pond or chain of ponds about 3½ miles in length. It has an area of 776 acres, and a watershed of 18.87 square miles. By the construction of a dam at the outlet it was raised 8 feet in 1848 and 2 feet additional in 1859. When the water was first taken no special preparation for its use for water supply purposes was made by the removal of soil, but in 1901-02, two areas aggregating about 80 acres where the water was shallow and the mud surface was exposed whenever the lake was drawn down, were improved at a cost of about $102-

SUDBURY DAM—UPPER SIDE.

Spillway of Sudbury Dam.

000 by the removal of the organic matter and excavating so as to give a depth of 10 feet of water at high water.

Situated near the lake are two ponds the waters of which can be drawn into the lake. The larger of these, Dudley Pond, has an area of 81 acres, and an available capacity of 250,000,000 gallons. Dug Pond has an area of 44 acres and an available capacity of 150,000,000 gallons.

Wachusett Aqueduct.

The Wachusett Aqueduct conveys water from the Wachusett Reservoir to the Sudbury Reservoir, a distance of 12 miles. The first two miles is a rock tunnel followed by seven miles of masonry aqueduct, including a bridge over the Assabet River and 3 miles of open channel. The tunnel section has a fall of 1 foot in 5,000, is lined for about one-half of its length with brickwork 12 inches thick, and where lined is 12 feet 2 inches wide and 10 feet 10 inches high. The masonry aqueduct has a fall of 1 foot in 2,500, and is 11 feet 6 inches wide and 10 feet 6 inches high. The open channel is 20 feet wide on the bottom and has side slopes of 3 horizontal to 1 vertical. All sections have a capacity of 300,000,000 gallons per day.

The tunnel and covered masonry sections of the aqueduct are built in the general shape of a horseshoe, the covered masonry section having a bottom and sidewalls of Rosendale cement concrete lined with 4 inches of brickwork, covered by a semi-circular arch of Portland cement concrete. The aqueduct crosses the Assabet River on a granite masonry bridge 359 feet long, consisting of seven arches each of 29½-foot span. The aqueduct on the bridge was lined with sheet lead to prevent leakage and consequent damage to the masonry from freezing. In order to prevent erosion of the bottom and sides of the open channel, they were faced with gravel where necessary, and two dams are located across the channel, one at the lower end where it enters the Sudbury Reservoir, and one about midway of its length. The superstructures on the aqueduct consist of two granite buildings, one covering a gaging chamber, the other the terminal chamber at the end of the covered masonry aqueduct.

WACHUSETT AQUEDUCT.

WACHUSETT AQUEDUCT—BRIDGE OVER ASSABET RIVER.

Weston Aqueduct.

This aqueduct conveys water from the Sudbury Reservoir to a point in the town of Weston a short distance west of the Charles River, and a little more than 10 miles from the State House. The distance from the Sudbury Dam to the terminus of the aqueduct is 13.42 miles. From the Sudbury Dam to the head-house at the beginning of the masonry aqueduct, a distance of 505.5 feet, the water is carried through three lines of cast-iron pipes 60 inches in diameter except for a distance of about 35 feet at the dam. For 3½ miles the masonry aqueduct of horseshoe shape is 10 feet wide by 9 feet 3 inches high, with a fall of 4 feet in 5,000. After passing under the New York, New Haven and Hartford Railroad the fall of the aqueduct is reduced to 1 foot in 5,000, and its size increased to 13 feet 2 inches by 12 feet 2 inches.

In crossing the valleys of the Sudbury River and a depression known as Happy Hollow, steel siphon pipes 7½ feet in diameter are substituted for the masonry structure. At the Sudbury River the pipe line is 3,617 feet long, and at Happy Hollow 1,139 feet. Three lines of pipe will be eventually required to carry the full flow of the aqueduct but only one line has now been laid.

Eleven and one-third miles from the Sudbury Dam the masonry aqueduct discharges into an open channel 1,400 feet long, 12 feet deep and 10 feet wide at the bottom, with gravel side slopes of 3 horizontal to 1 vertical. After passing through this channel, the water enters the Weston Reservoir which with the open channel, takes the place of the aqueduct for about a mile. At the lower end of the reservoir there is a screen chamber from which the masonry aqueduct extends 5,658 feet to the terminal chamber, from which pipes are used to convey the water into the Metropolitan District. Where the aqueduct is built in open trench or on embankments, the bottom and sidewalls are constructed of natural cement concrete lined with one 4-inch course of brick masonry and an arch of Portland cement concrete. On the line of the aqueduct there are five tunnels having an aggregate length of 12,165 feet lined throughout with concrete.

WESTON AQUEDUCT—7½-FOOT STEEL PIPE AT HAPPY HOLLOW SIPHON.

WESTON AQUEDUCT—7½-FOOT STEEL PIPE ARCH ACROSS SUDBURY RIVER.

Weston Reservoir—Screen Chamber at Outlet.

WESTON AQUEDUCT—TERMINAL CHAMBER.

Sudbury Aqueduct.

The Sudbury Aqueduct conveys water from Framingham Reservoirs Nos. 1, 2 and 3, located on the Sudbury River, to the Chestnut Hill Reservoir in the Brighton district of the city of Boston, a distance of 17.4 miles. It is of horseshoe shape, constructed of brick and stone masonry laid in cement mortar. From the beginning at Dam No. 1 to the gate-house at Farm Pond, a distance of 1½ miles, the aqueduct is 7 feet 6 inches wide and 6 feet 10½ inches high, and has a fall of 1 foot in 2,275. From the Farm Pond gate-house to Chestnut Hill Reservoir it is 9 feet wide, 7 feet 8 inches high, and has a fall of 1 foot per mile. It has a capacity of 103,000,000 gallons in 24 hours.

The aqueduct crosses the valleys of Waban Brook and the Charles River on granite masonry bridges. The Waban valley bridge is 536 feet long, and consists of 9 semi-circular arches of 44 feet 8 inches span. The Charles River bridge is 475 feet long, 79 feet above the river, and is formed by 7 arches, the largest one having a span of 129 feet. At the valley of Rosemary Brook two lines of 48-inch and one line of 60-inch cast-iron pipe, each line being 1,800 feet long, take the place of the masonry structure. There are four tunnels on the line of the aqueduct the longest of which is 4,635 feet in length.

This aqueduct was built by the City of Boston, and was completed and first used in 1878.

Cochituate Aqueduct.

This aqueduct is 13.7 miles long and extends from Lake Cochituate to the Chestnut Hill Reservoir. It is egg shaped in section, 5 feet wide, 6 feet 4 inches high, and is built of brick masonry 8 inches in thickness, with the exception of a tunnel 2,410 feet long, which is unlined, and at the crossing of the Charles River where four lines of cast-iron pipes 1,100 feet long are substituted for the masonry structure. Two of these are 30 inches in diameter, one 36 inches and one 40 inches. The masonry portion of the aqueduct has a fall of 1 foot in 20,000.

Chestnut Hill Reservoir.

The Chestnut Hill Reservoir is located in the Brighton district of the city of Boston, about five miles from the State House. It receives water from the Sudbury and Cochituate aqueducts, and serves as a storage reservoir from which the pumps at the high and low-service stations draw their supplies. This reservoir was built by the City of Boston, and completed in the year 1870. Its high water mark is 134 feet above Boston city base, and previous to the year 1900 the greater portion of the city of Boston was supplied from this reservoir by gravity.

The reservoir consists of two basins having areas of 87½ and 37½ acres respectively. It was constructed by building a dam 2,000 feet long, with a maximum height of 35 feet, across a valley, removing the soil from the enclosed basin and paving the slopes. The dam is built of earth put on in layers, watered and rolled, and near the center of the dam is a core of clay puddle 10 feet thick at the base and 4 feet at the top. The slopes of both basins of the reservoir are covered with stone paving 2½ feet in thickness, which extends 8½ feet from the top of the bank measured vertically.

Connected with the reservoir there are five gate-chambers through two of which water is admitted to the reservoir from the Sudbury and Cochituate aqueducts; one contains gates which control the flow between the two basins and also admits water from the Cochituate aqueduct, and through one water is drawn to the two pumping stations. The large gate-chamber at the east end of the reservoir was used as an effluent gate-chamber previous to the year 1900, while water was supplied from the reservoir by gravity, but at present all the gates are closed.

Pumping Stations.

All water delivered into the Chestnut Hill Reservoir by the Sudbury and Cochituate aqueducts is pumped at two stations located on the southeasterly side of the reservoir. At one station water is pumped to supply the higher land in the southern portion of the Metropolitan District; at the other it is pumped into mains leading to Spot Pond, which is the

CHESTNUT HILL RESERVOIR, WITH HIGH AND LOW SERVICE PUMPING STATIONS.

CHESTNUT HILL LOW SERVICE PUMPING STATION.

principal distributing reservoir for the lower portion of the District. On the shore of Spot Pond, in Stoneham, there is a pumping station from which water is pumped to a reservoir supplying the higher levels in the northern part of the District. At two smaller stations, one in the West Roxbury district of Boston and one in the town of Arlington, water is pumped to supply small districts situated above the elevation supplied from the larger stations at Chestnut Hill and Spot Pond.

The low-service pumping sation at the Chestnut Hill Reservoir has exterior walls of buff Bedford Indiana limestone. The building contains an engine room 134 feet by 60 feet, 41½ feet in height from the floor to the under-side of the roof trusses, a boiler room 62 feet by 40 feet, a coal house 89½ feet by 48 feet, a dynamo room 38 feet by 17 feet, and a tower 19 feet square in which is located a steel equalizer and overflow tank 13½ feet in diameter and 33 feet high, having a capacity of 31,000 gallons. The interior facing of the engine room walls is of buff brick with red brick trimmings, and the floor is of green slate tile. The chimney is 125 feet high, 13 feet in exterior diameter at the base and 8 feet at the top under the cap. The flue is 4 feet 6 inches in diameter.

The machinery consists of three 35,000,000-gallon vertical triple expansion crank and fly-wheel engines, designed and built by the Holly Manufacturing Company of Lockport, N. Y., and three vertical fire tube boilers designed by Dean and Main and built by the Atlantic Works of East Boston. The engines have steam cylinders 17, 31¼ and 48 inches in diameter, pump plungers 37 inches in diameter, and both pistons and plungers have a stroke of 60 inches. These engines draw their supply from the Chestnut Hill Reservoir, and raise it from 45 to 60 feet. On the contract trial they gave a duty of 156,322,000-foot pounds per 100 pounds of dry coal. The boilers are 97 7/8 inches inside diameter, 29½ feet high over all, and contain 384 2-inch tubes 15 feet long. A Green economizer, with 144 tubes, is located in the smoke flue between the boilers and the chimney. The coal house has a capacity of 1,000 tons, and is so arranged that loaded cars are run into the building about 15 feet above the floor.

High Service Pumping Station at Chestnut Hill Reservoir.

The high-service pumping station has exterior walls of pink Milford granite with brownstone trimmings. The engine room contains two 8,000,000-gallon Gaskill engines built by the Holly Manufacturing Company, of Lockport, N. Y., one 20,000,000-gallon triple expansion engine designed by E. D. Leavitt and built by the Quintard Iron Works, of New York, N. Y., and one 30,000,000-gallon vertical, triple expansion, crank and fly-wheel engine, designed and built by the E. P. Allis Company of Milwaukee, Wisconsin. The boiler room contains one boiler of the Belpaire type, two internally fired verticle fire-tube boilers, and two externally fired fire-tube boilers.

The principal dimensions and other data relating to the engines and boilers at this station are as follows:

	Engines.		
	Gaskill.	Leavitt.	Allis.
Erected	1887	1895	1898
Diameter of high pressure cylinder (ins.)	21	13 7-10	30
Diameter of intermediate pressure cylinder (ins.)	..	24.375	56
Diameter of low pressure cylinder (ins.)	42	39	87
Diameter of pump plunger (ins.)	25	17.5	42
Stroke of pumps	36	48	66
Normal revolutions per minute	18½	50	18
Cost	$24,000	$140,000	$140,000
Duty per 1,000 pounds of dry steam on official trial (foot pounds)			178,497,000
Duty per 100 pounds of coal (foot pounds)			173,869,000

	Boilers.		
	Belpaire.	Vertical Tubular.	Horizontal Tubular.
Diameter (ins.)	90	98	64
Length in feet	34.33	24.33	18.42
Thickness of shell (ins.)	.8	27/32	17/32
Number of tubes	201	392	102
Diameter of tubes (ins.)	3	2	3
Length of tubes (feet)	16	14	17.88
Heating surface (sq. ft.)	3000	2207	1475

These engines pump water from the Chestnut Hill Reservoir for the supply of the southern high-service district, raising it from 120 to 130 feet into the Waban and Fisher Hill reservoirs.

The Spot Pond pumping station building has exterior walls

of gray Roman brick, with trimmings of buff Indiana limestone above a heavy base of pink Milford granite. The roof is covered with red Spanish tiles. The building contains an engine room 105 feet by 60 feet, a dynamo room 49 feet by 16 feet, a boiler room 53 feet by 49 feet, and a coal house 71 feet 8 inches by 40 feet, having a storage capacity of 1,000 tons. The chimney is 125 feet high, 11 feet square at the base, 9 feet at the top, with a flue 4 feet in diameter. The engine room contains at present two engines, one of 10,000,000 gallons daily capacity, designed by E. D. Leavitt for the City of Boston, and erected by the Blake Manufacturing Company in 1895 at the Mystic pumping station, whence it was removed in 1899, and one of 20,000,000 gallons daily capacity erected by the Holly Manufacturing Company of Lockport, N. Y. The engine room contains space for a third engine.

The Leavitt engine has steam cylinders 21 inches and 42 inches in diameter, operating two differential plunger pumps. The plungers have diameters of 14 7/8 and 21 inches, and both pump plungers and steam pistons have a stroke of 48 inches. The Holly Manufacturing Company's engine has steam cylinders 22 inches, 41½ inches and 62 inches in diameter, pump plungers 30½ inches in diameter, and both pistons and plungers have a stroke of 60 inches.

The boiler room contains three vertical internally fired fire tube boilers 92 inches in diameter, 29 feet 4½ inches long, containing 256 2¼-inch tubes 15 feet long. The boiler feed water is heated by passing through a Green economizer containing 144 tubes. By these pumps water is raised from Spot Pond 108 feet to the Fells Reservoir, and 137 feet to the Bear Hill Reservoir, and from these reservoirs distributed to the elevated portions of the northern part of the Metropolitan District.

The Arlington pumping station is located in the town of Arlington, near the Boston and Maine Railroad. It contains two duplex direct acting pumps, each of 750,000 gallons capacity in 24 hours, one boiler of the locomotive type 56 inches in diameter, 18 feet long, containing 60 4-inch tubes, and one vertical internally fired boiler 72 inches in diameter, 9 feet 3 inches long, containing 350 2-inch tubes 6 feet long. These pumps take water from a main under a pressure of about 30 pounds, and raise it to a standpipe the top of which is 443

Spot Pond Pumping Station.

feet above Boston city base, giving a pressure of about 160 pounds on the pumps.

The West Roxbury pumping station, located in the West Roxbury district of the city of Boston, contains two compound duplex condensing pumps made by Henry R. Worthington, each having a capacity of 1,000,000 gallons in 24 hours. Steam is supplied by two boilers 54 inches in diameter, 9 feet long, containing 184 2-inch tubes. These pumps draw their supply from a main under a pressure of about 38 pounds, and raise it under a pressure of 97 pounds to a standpipe the top of which is 376 feet above Boston city base.

Distributing Reservoirs.

Connected with the Metropolitan Water Supply there are six reservoirs and two standpipes belonging to the Metropolitan Works, and five reservoirs and eleven standpipes belonging to the several cities and towns. Two of the local reservoirs and several of the standpipes are not in use at the present time.

The location, elevation and capacity of all the distributing reservoirs is as follows:

Reservoirs.

Name. Location.	Elevation.	Capacity.	Service.	Owner.
Spot Pond, Stoneham..	163	1,890,000,000	Low	Met. W. W.
Mystic, Medford	157	26,000,000	Low	Met. W. W.
Fells, Stoneham	271	41,353,000	No. high	Met. W. W.
Bear Hill, Stoneham....	300	2,452,000	No. high	Met. W. W.
Waban Hill, Newton...	264.5	13,500,000	So. high	Met. W. W.
*Forbes Hill, Quincy...	192	5,116,000	So. high	Met. W. W.
Fisher Hill, Brookline.	251	15,400,000	So. high	Boston.
Chelsea, Chelsea	196.6	1,000,000	No. high	Chelsea.
Revere, Revere	194.5	1,818,000	No. high	Revere.
*E. Boston, E. Boston..	...	5,600,000	Low	Boston.
*Parker Hill, Roxbury.	229	7,200,000	So. high	Boston.

Standpipes.

Name. Location.	Elevation.	Capacity.	Service.	Owner.
Forbes Hill, Quincy.....	252	340,000	So. high	Met. W. W.
Arlington, Arlington....	443.2	564,000	No.Ex.high	Met. W. W.
W. Roxbury, W. Roxb'y	376.3	135,300	So.Ex.high	Boston.
Orient Hgts., E. Boston	204.4	135,300	No. high	Boston.
†Everett, Everett	221.9	141,000	No. high	Everett.
Lexington, Lexington...	385.3	185,000	No.Ex.high	Lexington.
Lexington, Lexington...	387.4	105,750	No.Ex.high	Lexington.
*Malden, Malden	250.4	1,156,700	No. high	Malden.
†Medford, Medford	232.5	432,000	No. high	Medford.
Nahant, Nahant	170	502,300	No. high	Nahant.
Quincy, Quincy	249	432,000	So. high	Quincy.
Swampscott, Swampsc't.	200	611,000	No. high	Swampscott.
Watertown, Watertown.	229.7	376,000	So. high	Watertown.

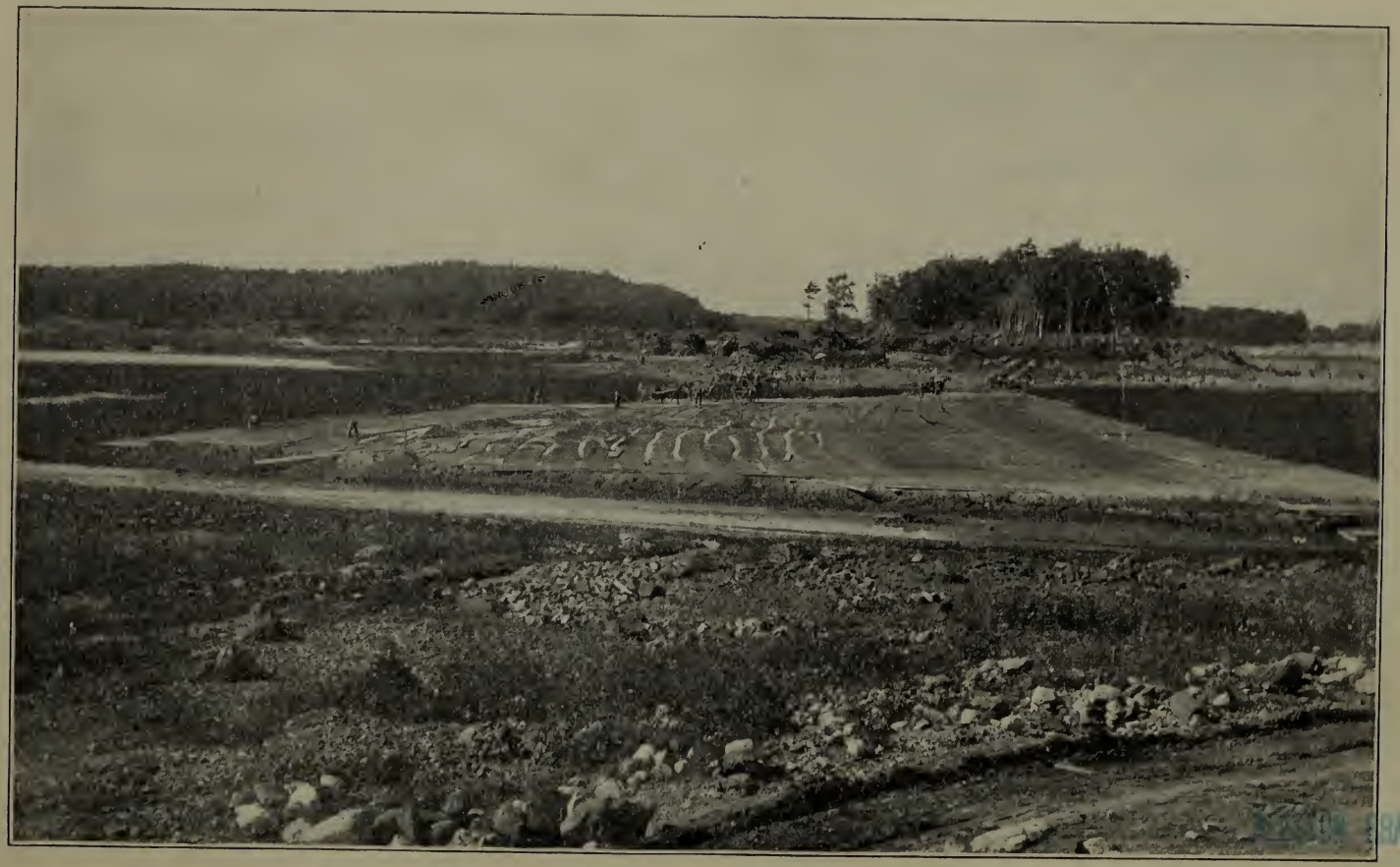
* Kept full of water for use in emergencies. † Not in use at present.

Spot Pond.

Spot Pond, the largest distributing reservoir, has an area of 308.7 acres and is situated in the northern part of the Metropolitan District in the town of Stoneham, about eight miles from the State House and eleven miles from the Chestnut Hill Reservoir. It has been formed by raising and improving a large natural pond which, previous to the construction of the Metropolitan Works, was used as a source of supply for the cities of Malden, Medford and the town of Melrose. The improvement of the pond was made by lowering its surface 12 feet, thus exposing the greater part of the bottom, and then excavating the mud so as to give a clean gravel or sand bottom over the greater part of the exposed area. In places where the mud was so deep that it could not be removed without going below the level of the water in the pond, the mud was covered with clean gravel or sand 12 inches in thickness. The earth was also excavated from the shallow portions of the pond so as to give everywhere a depth of 15 feet of water when the pond is full.

The pond was raised 9 feet above its old level, necessitating the building of six dams with concrete corewalls from 165 to 621 feet long, and from 10 to 28 feet in height, and four earth dikes; also the construction of a system of drainage to care for water which, by the construction of the dams, is prevented from entering the pond. This drainage system consists of 2,200 feet of open channel, 1,600 feet of 24-inch vitrified pipe, 1,050 feet of concrete masonry conduit 4 feet wide, 3½ feet high, and 2,400 feet of 30-inch cast-iron pipe.

The drains collect the water from 766 acres which formerly drained into the pond, and discharge it into the brook which was the outlet of the pond previous to its improvement. Water enters and leaves the pond at two points located about 3,000 feet apart. At each of these points there is a concrete masonry chamber located at the shore, in which there are sluice gates for controlling the flow of water. From each chamber two inlets into the pond are provided so as to draw water from different depths. From the east chamber there is a concrete masonry conduit 5 feet high, 4.5 feet wide, extending 565 feet into the pond, with its invert 25.2 feet below high water. The



Spot Pond—Covering D eep Mud With Sand.

SPOT POND—VIEW OF NORTHWESTERLY PART AFTER IMPROVEMENT.

high level inlet consists of a 48-inch pipe 58 feet in length. From the south gate-chamber a concrete masonry structure containing two conduits placed one above the other, extends 200 feet into the pond. The invert of the lower conduit is 26 feet below high water, and the opening into the upper conduit is in the top of the masonry structure 12 feet below high water. From the gate-chambers cast-iron pipes convey the water into the Metropolitan District.

Fells Reservoir.

The Fells Reservoir, which is the principal distributing reservoir for the northern high-service district, is located in the Middlesex Fells about 2,500 feet east of Spot Pond, and its high water level is 271 feet above Boston city base, or 108 feet above the level of Spot Pond. It covers 8½ acres located in a natural rocky basin which, by the construction of five dams having an aggregate length of 930 feet, has been converted into a reservoir of irregular outline, which, when full, has a capacity of 41,353,000 gallons. All of the dams have corewalls of natural cement concrete 3 feet thick at the top, which are carried down with a batter of 1 in 12 on each side to the solid rock for their entire length. The tops of the walls are 2 feet above high water, and their heights vary from 15 to 34 feet. The faces of the walls next the reservoir are plastered with Portland cement mortar. Embankments of selected material put on in 4-inch layers and rolled with grooved rollers, were built on both sides of each corewall and covered, on the side next to the reservoir, with a 4 to 1 slope of fine broken stone 10 inches in thickness, extending from a point 1½ feet above high water mark to a point 4 feet below, and below that point the embankments have a slope of 2 to 1 covered with Portland cement concrete 4 inches in thickness. At elevation 265 or 6 feet below high water the reservoir is divided by a natural ridge of rock and two walls of Portland cement concrete into two basins, the easterly of which has a capacity of 10,440,000 gallons, and the westerly 15,359,000 gallons. Water is supplied to the reservoir from the pumping station at Spot Pond through a 36-inch force main which enters the north end of the reservoir and is laid through the west

FELLS RESERVOIR—CONCRETE CORE WALL AND PARTIALLY CONSTRUCTED EMBANKMENT.

basin, supported on concrete piers, to the gate-house at the south end of the reservoir. The portion of the gate-house below the ground level is built of Portland cement concrete faced on exposed sides with granite to a point 6 feet below high water mark. The structure contains 6 chambers provided with gates, so that the water can be delivered from the pumps into either basin or to the District, and can also be drawn from either basin independently. The gate-house also contains a measuring weir 6 feet in length for determining the capacity of the pumping engines. The superstructure of the gate-house is built of seam-faced granite with trimmings of Deer Isle granite, and the roof is covered with red tiles.

Mystic Reservoir.

This reservoir is situated near Tufts College in the city of Medford, and was built in 1863 by the City of Charlestown in connection with works for supplying water from Mystic Lake. It was taken from the city of Boston and became a part of the Metropolitan Water Works on January 1, 1898, and is used as a low-service reservoir, being 6 feet lower than Spot Pond. It is about 550 feet long by 350 feet wide at the level of the granite coping which surrounds the reservoir on the top of the embankment. The embankments are of earth, 19 feet 4 inches wide at the top, with 1½ to 1 slopes. The reservoir is lined with clay puddle 24 inches in thickness, covered on the bottom with Rosendale cement concrete 3 inches in thickness, and on the slopes with a paving of brick 8 inches thick laid in cement mortar. The reservoir is divided into two basins by an embankment, the top of which is 5 feet below high water mark. The depth of water in the reservoir when full is 22 feet. A gate-chamber at the south-east corner of the reservoir contains gates for controlling the flow of water to and from the reservoir, and there is also a chamber in the embankment on the easterly side of the reservoir through which water was pumped into the reservoir when it was used in connection with the supply from Mystic Lake.

Forbes Hill Reservoir.

This reservoir is situated in the city of Quincy, and is used

for the storage of water to be used in case of accident to the pumping machinery or to the pipes leading from the pumping station at Chestnut Hill Reservoir ten miles distant. Water is stored and the pressure equalized for the ordinary use of the city in two standpipes in which the water is maintained at a level of about 50 feet above the high water level of the reservoir, so that it is only in cases of emergency that water is drawn from the reservoir. It is oblong in shape, 350 feet long and 150 feet wide at the top of the inner line of the embankment. The embankments are built of clayey hard-pan excavated from the reservoir, placed in 4-inch layers and thoroughly rolled. They are 17 feet wide at the top, with the inner slopes 1¾ horizontal to 1 vertical, and the outer slopes 2 horizontal to 1 vertical. The bottom and inner slopes of the reservoir are covered with concrete extending on the slope 2 feet vertical above high water. The concrete is in two layers between which there is one-half an inch of Portland cement plaster. On the bottom of the reservoir the lower layer is of natural hydraulic cement concrete 4 inches in thickness, the upper layer of Portland cement concrete also 4 inches in thickness. On the slopes both layers are made of Portland cement concrete, the lower layer being 6 inches thick, the upper layer 24 inches thick at the top and 5 inches thick from about one-third of the way down the slope to the bottom. Constructed in the embankment at the west end of the reservoir and entirely below the top of the embankment, there is a gate-chamber of concrete masonry containing pipes and valves for controlling the flow of water into and out of the reservoir. A granolithic walk, 6 feet in width, surrounds the reservoir at the top of the embankment.

Near the reservoir there is located a standpipe 30 feet in diameter, 64 feet 4 inches high, enclosed by a granite masonry tower 77 feet high, of pleasing architectural appearance, which acts as a protection against freezing of the water, and affords an observatory from which the public can enjoy extended views of the surrounding country.

Bear Hill Reservoir.

This reservoir is situated in the Middlesex Fells in the town

Forbes Hill Reservoir and Water Tower.

of Stoneham, about 1,500 feet west of the northerly end of Spot Pond. It is 29 feet higher than the Fells Reservoir, and is now used for supplying water to the town of Stoneham. It was formed by constructing two dams of concrete masonry and earth across a depression in the rocky ridge which forms the summit of Bear Hill, thus enclosing an area of about three-fourths of an acre. The bottom of the reservoir is almost entirely rock in which there are numerous seams. These seams were very carefully plastered with cement mortar, and the whole bottom washed with Portland cement grout. The maximum depth of water in the reservoir is 15 feet. The concrete walls forming the dams are vertical on the water side from the bottom to a point 5 feet below high water mark, and above that point slope upward and outward with an incline of 1 to 1 to a height 2 feet above high water. The upper 5 feet of the slope is paved with stone, from the excavations, laid in cement mortar. A small chamber built of concrete masonry with a superstructure of granite, containing sluice gates for controlling the flow of water into and out of the reservoir, is located near the center of the north dam.

Waban Hill Reservoir.

This reservoir is located on Waban Hill in the city of Newton, about 7,900 feet from the high-service pumping station at Chestnut Hill, and is used in connection with the southern high-service of the Metropolitan District. It was built by the city of Newton in 1876, and purchased for the Metropolitan Water Works in 1900. It was constructed with earth embankments 14 feet wide at the top, having 1½ to 1 slopes on both inner and outer slopes, the inner slope being covered with granite paving 15 inches in thickness, bedded in 6 inches of broken stone, under which there is 24 inches of puddle made from the clayey gravel excavated on the reservoir site. The bottom of the reservoir is covered with 6 inches of concrete resting on 24 inches of puddle. The depth of water in the full reservoir is 16.7 feet, the high water elevation is 264.50 above Boston city base, and its capacity is 13,500,000 gallons.

Pipe Lines.

Water is distributed to the several cities and towns through 83.80 miles of pipes from 60 inches to 12 inches in diameter.

The lengths and sizes of the principal lines of pipe are as follows:

	Service.	Size (ins.)	Length (feet.)
Pumping station at Chestnut Hill to Spot Pond, two lines:	Low	60	6,432
West line	Low	48	46,660
	Low	*36	800
	Low	48	59,534
East line	Low	*36	5,160
Terminus of Weston Aqueduct to connection with two 48-inch mains at Chestnut	Low	60	2,626
Hill Reservoir	Low	48	36,800
	Low	48	7,220
Supplying low-service to Everett, Chelsea,	Low	42	8,044
East Boston and Charleston from 48-inch	Low	30	280
main in Malden	Low	24	6,500
	Low	20	1,910
Pumping Station at Chestnut Hill to Forbes Hill Reservoir, supplying Quincy, Milton and the higher portions of Boston:			
Pumping station to Forest Hills	So. high	48	18,339
Forest Hills to River Street	So. high	36	17,400
River Street to Forbes Hill Reservoir.	So. high	24	15,620
Pumping Station at Chestnut Hill Reservoir to Waban Hill Reservoir, thence to Watertown and Belmont:			
Pumping Station to Waban Hill Reservoir	So. high	36	8,317
Waban Hill Reservoir to Watertown..	So. high	20	12,704
Watertown to Belmont line	So. high	16	4,217
Pumping Station at Spot Pond to Fells Reservoir	No. high	36	4,785
Fells Reservoir to Malden, Medford, Somerville, Everett, Chelsea, Revere, Breed's Island, Swampscott and Nahant:			
Fells Reservoir to Elm Street, Malden.	No. high	36	7,305
Elm Street, Malden, to Boston Avenue, Medford	No. high	20	15,282
Boston Avenue, Medford, to Cedar Street, Somerville	No. high	16	4,335
Elm Street, Malden, to Hancock and Cross Streets, Malden	No. high	30	7,289
Hancock and Cross Streets, Malden, to Broadway, Everett	No. high	24	4,319
Broadway, Everett, to Fenno Street, Revere	No. high	20	9,740
Fenno Street, Revere, to Beachmont, Revere	No. high	16	10,284
Beachmont, Revere, to Breed's Island.	No. high	12	3,812
	No. high	20	113
Beach Street, Revere, to Nahant and	No. high	16	30,425
Swampscott	No. high	12	3,780
Fenno Street, to Revere Reservoir	No. high	12	865
Fenno Street to Chelsea Reservoir	No. high	16	2,528

	Service.	Size (ins.)	Length (feet.)
Spot Pond Pumping Station to Bear Hill Reservoir and Stoneham:			
Pumping Station to Main and South Streets, Stoneham	No. high	24	5,876
Main and South Streets to Bear Hill Reservoir	No. high	20	1,638
Main and South Streets to Stoneham..	No. high	20	4,754
Mystic Reservoir to Walnut Street, Somerville, two lines:			
North line	Low	24	10,860
South line	Low	30	11,200
Mystic Reservoir to Arlington:			
Reservoir to Mystic River	Low	30	3,610
River Crossings	Low	36	566
Mystic River to Parkway	Low	24	3,269
Parkway to Pumping Station	Low	20	9,876

*At the crossing of the Charles River on the west line, and of the Charles, Mystic and Malden rivers on the east line, two parallel lines of 36-inch pipe are used in place of one line of 48-inch pipe.

Connected with these mains, there are 543 valves for controlling the flow of water and 53 Venturi meters of sizes varying from 6 to 48 inches, by means of which a continuous record is kept of the quantity of water used in each of the eighteen municipalities supplied with water.

With the exception of a 30-inch pipe-line, 11,200 feet long, between the Mystic Reservoir and Walnut Street, in Somerville, which is wrought iron, lined and covered with cement, and 39 feet of 36-inch wrought-iron pipe at a brook crossing, all of the distributing pipes belonging to the Metropolitan Works, are made of cast iron, and laid with leaded joints. The 36-inch pipes used in the crossing under the Charles, Mystic and Malden rivers, which are navigable streams, are 1.65 inches in thickness. In these pipe-lines, some of the joints are of the ordinary bell and spigot form, some have the spigots turned to a slight taper and forced into a leaded socket, and some have spherical spigots leaded into sockets, so as to make a flexible ball and socket joint.

The two lines of 24-inch pipe which pass under the Chelsea Creek between Chelsea and East Boston, have flexible leaded joints on each pipe. The line laid by the City of Boston in 1870 has joints which are flexible only in a vertical plan; those on the line laid in 1900 by the Metropolitan Water and Sewerage Board, have the Ward ball and socket joint.

The 24-inch pipe-line crossing the Mystic River between

Thirty-six-inch Pipes Crossing Mystic River.

Chelsea and Charlestown, is laid under the channel in a tunnel 6 feet in diameter and 145 feet long.

The distribution systems in the several cities and towns which are supplied with water from the Metropolitan works contain 1,447 miles of pipes, 147,794 service pipes, 13,492 fire hydrants and 17,976 water meters.

Measures Taken to Improve the Quality of the Water and to Prevent its Pollution.

In addition to the removal of soil from the bottom of the storage reservoirs, the measures taken to improve the quality of the water and to prevent its pollution are:

1st. The construction of ditches for the purpose of draining the swamps in the watersheds;

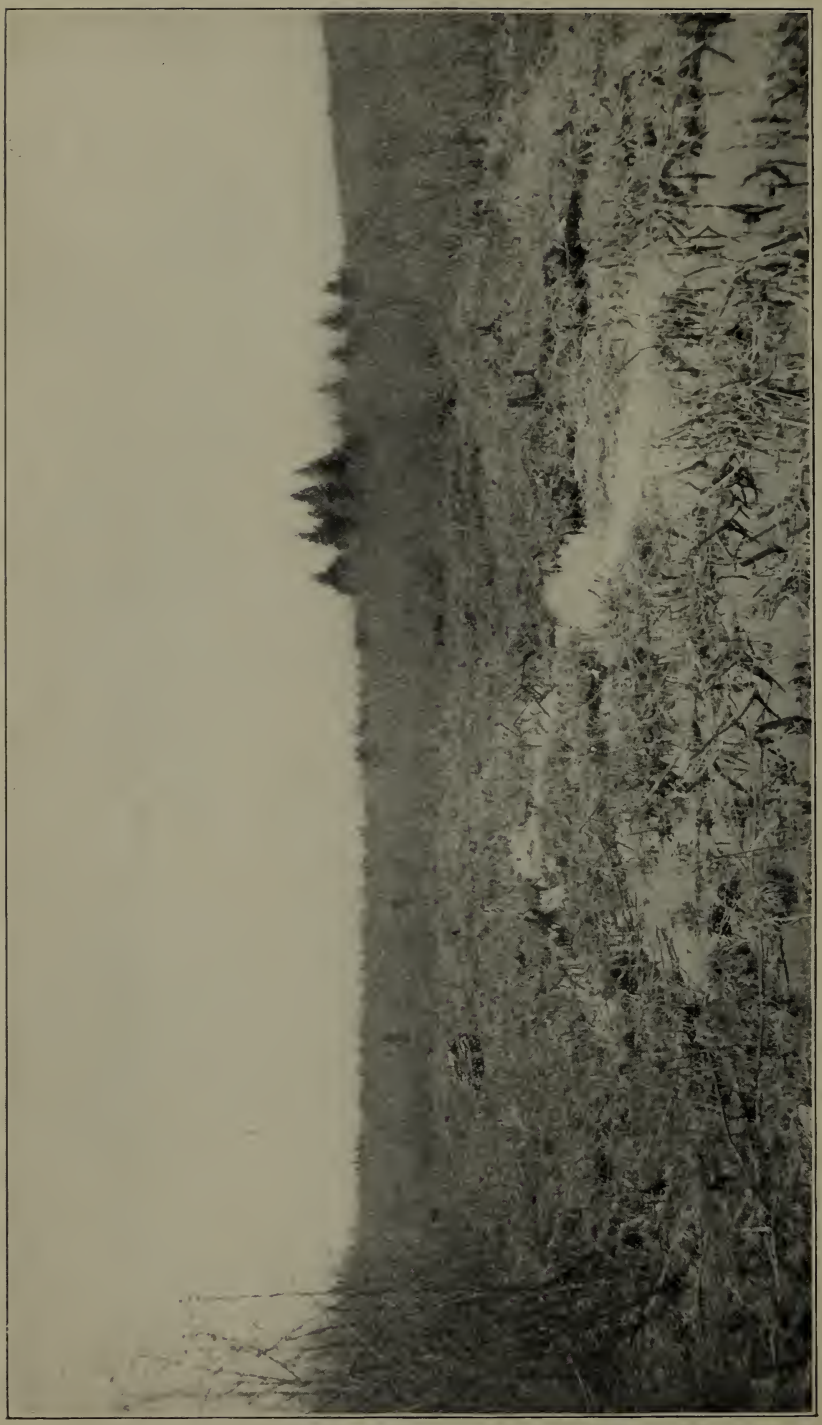
2d. The construction and maintenance of works for filtering water of objectionable quality before permitting it to enter the reservoirs;

3d. A constant and careful inspection of the watersheds for the purpose of elminating any possible sources of pollution.

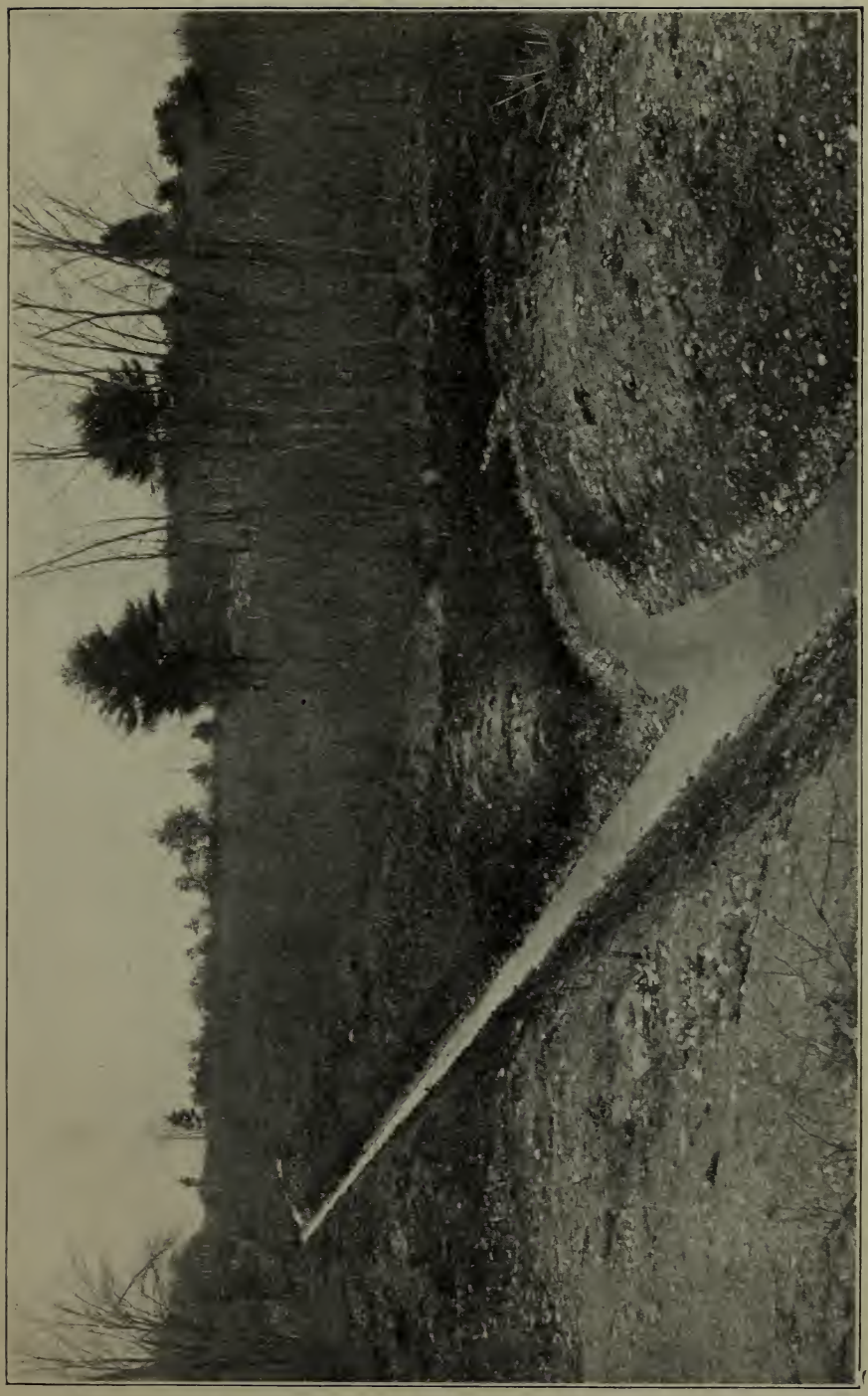
Where the water passes through swamps it takes up organic matter and acquires a deep brownish color. For the purpose of preventing this several of the larger swamps have been drained by the construction of ditches generally placed near the edges of the swamps so as to intercept the water from the uplands and convey it to the reservoirs without deterioration.

On the Sudbury watershed swamps tributary to the open channel of the Wachusett Aqueduct, having an aggregate area of 667 acres, are drained by 15.55 miles of ditches, and other swamps draining into the Sudbury Reservoir and into Framingham Reservoir No. 3, having an area of 270 acres, are drained by 9 miles of ditches. On the Wachusett watershed 132 acres of swamp area are drained by 2.85 miles of ditches.

These ditches are of sufficient size to convey all water which is likely to reach them except during times of extremely high flow. They are constructed with a board bottom 12 inches wide, with triangular strips of wood 3 inches high on each side forming a footing for stone paving on the sides of the ditches which have slopes of 2 horizontal to 1 vertical. The depth of the ditches is generally from 1½ to 2½ feet.



SWAMP DRAINAGE—SWAMP BEFORE DRAINAGE.



Swamp Drainage—Swamp After Drainage.

Residing on the areas which drain into the several reservoirs from which the water supply is drawn, there are the following populations:

POPULATION.

	Total.	In dwellings not connected with sewer.	Per sq. mile in dwellings not connected with sewer.
Wachusett watershed	5,772	5,772	49.
Sudbury watershed	21,131	10,575	140.6
Cochituate Watershed ...	15,508	6,521	328.7

The thickly settled portions of Westborough and Marlborough on the watershed of the Sudbury River, and of South Framingham and Natick on the watershed of Lake Cochituate, are provided with systems of sewerage by which the house drainage is carried outside the limits of the areas draining into the Metropolitan sources of supply.

Running through the thickly populated portions of the city of Marlborough and the town of Natick there are brooks which receive street washings and other surface drainage which it is undersirable to have run directly into water which is to be used for domestic purposes. Works have been constructed and are continuously operated for filtering the water of these brooks before admitting it into the reservoirs. The water of Marlborough Brook, which drains an area of about two square miles at the upper end of the Sudbury Reservoir, is filtered previous to its admission to the reservoir on twenty-four filter-beds having an aggregate area of 14 acres. The water flows from the brook by gravity onto the beds, and after passing through the sand or gravel is collected in under-drains and conveyed to the river.

The water of Pegan Brook, which runs through the village of Natick and enters the south end of Lake Cochituate, is pumped on to five filter-beds having an aggregate area of 2.9 acres. The pumping machinery used consists of two Lawrence centrifugal pumps, one 8-inch and one 10-inch, directly connected to 5-inch by 10-inch by 7-inch vertical Cross compound engines of the marine type.

Chemical examinations of the water in the different reservoirs are made monthly by the State Board of Health, and

MARLBOROUGH BROOK FILTER BEDS.

observations of the color and odor of the water, and of the number and character of the organisms present, are made weekly in the laboratory of the Metropolitan Water and Sewerage Board.

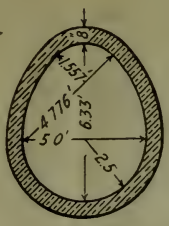
Clinton Sewerage.

The town of Clinton, having a population in 1905 of 13,105, formerly discharged its sewage directly into the Nashua River at points below the site of the Wachusett Dam. The diversion of the water for the use of the Metropolitan Water Works reduced the quantity flowing down the river below the dam to such an extent that the direct discharge of sewage into the river would have caused an annoyance to the persons resident upon its banks. Provision was therefore made in the Metropolitan Water Act for the diversion of this sewage from the river, and disposal works have been built and are maintained by the Metropolitan Water and Sewerage Board.

An intercepting sewer composed of 3,661 feet of 20-inch and 853 feet of 24-inch vitrified pipe, and 1,120 feet of 30-inch brick sewer, conveys the sewage to a reservoir 100 feet in diameter, holding 600,000 gallons, from which it is raised 55 feet by means of a 3,000,000-gallon compound duplex pumping engine built by the George F. Blake Manufacturing Company, through 2,191 feet of 18-inch cast-iron pipe, and discharged intermittently upon twenty-five filter-beds having an aggregate area of 23.5 acres. From the underdrains of the beds the filtered water flows to the river. The daily average quantity of sewage treated in 1905 was 643,000 gallons.

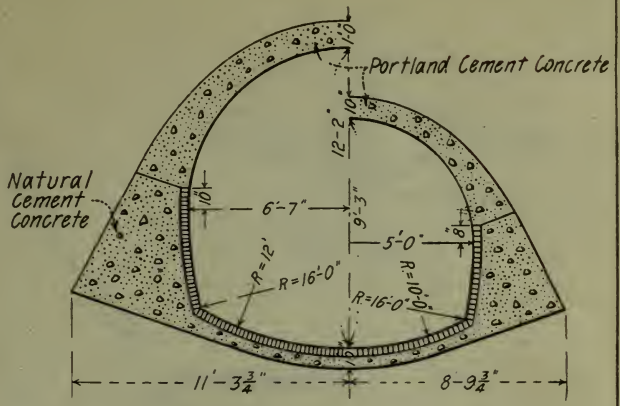
Future Supply of the Metropolitan Water District.

The scheme recommended by the State Board of Health for furnishing an additional supply of water for the Metropolitan District was adopted not only on account of its adequacy for furnishing a large immediate addition to the supply, but also on account of the opportunities it afforded for supplying the needs of the future. Lying between the Sudbury and Nashua watersheds is the Assabet watershed with an estimated daily average capacity of 28,000,000 gallons. West of the Nashua watershed are the Ware and



Cochituate Aqueduct

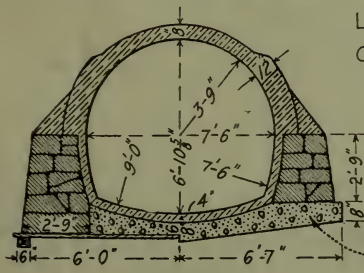
GRADE 1: 20000



Weston Aqueduct

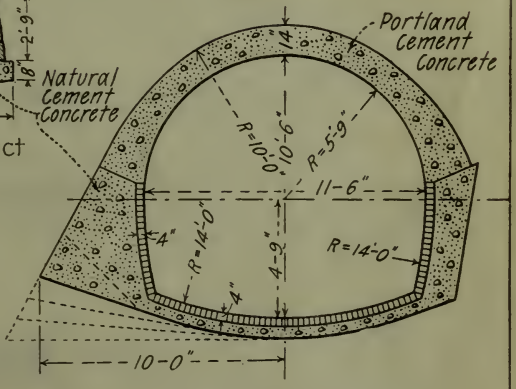
Lower Portion GRADE 1: 5000

Upper Portion GRADE 1: 1250



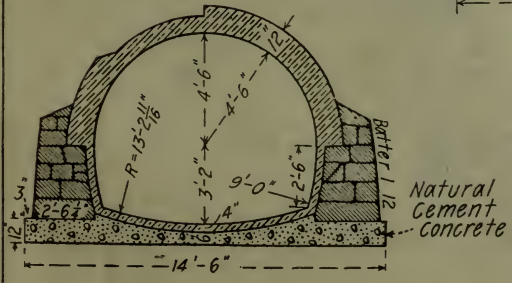
Sudbury Supply Aqueduct

GRADE 1: 2275



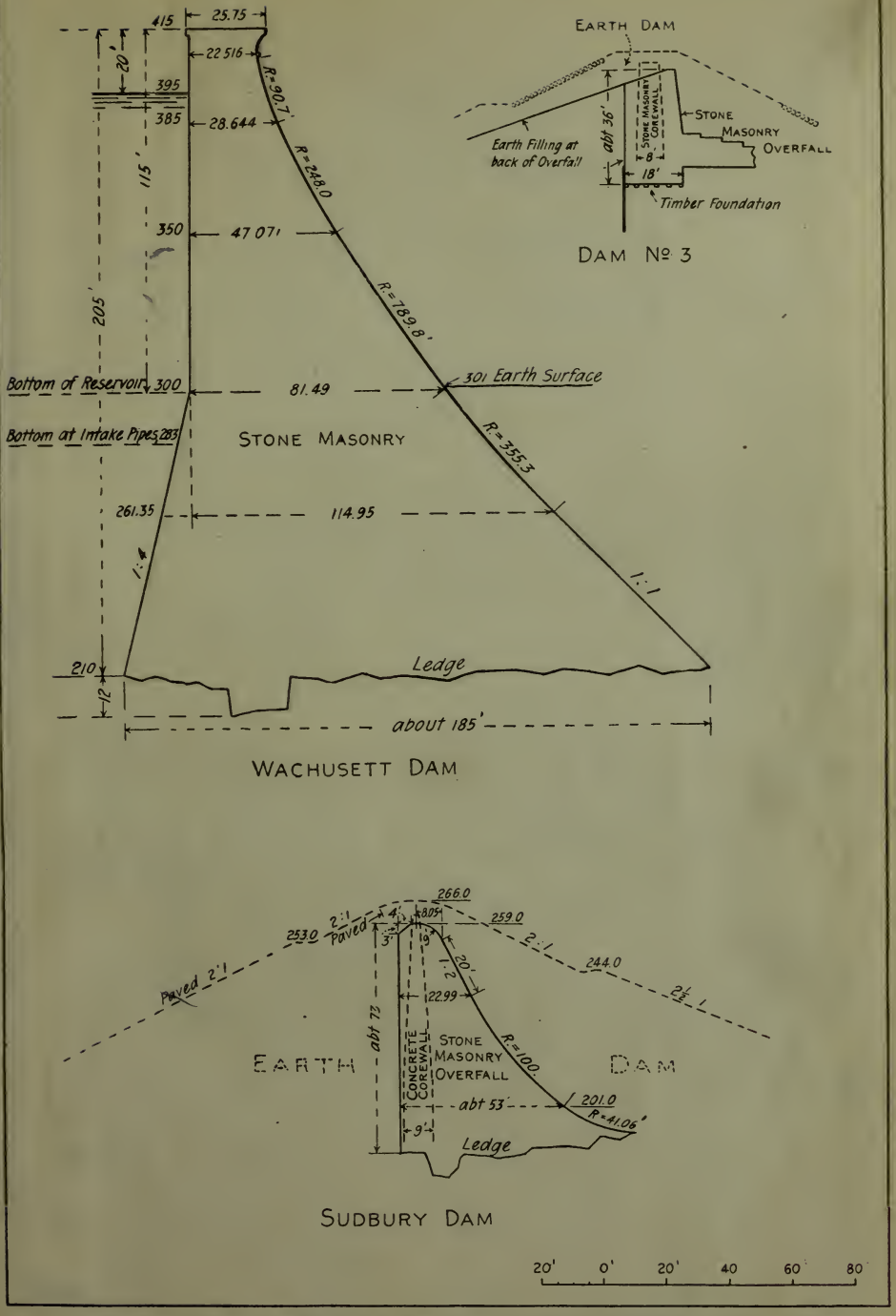
Wachusett Aqueduct

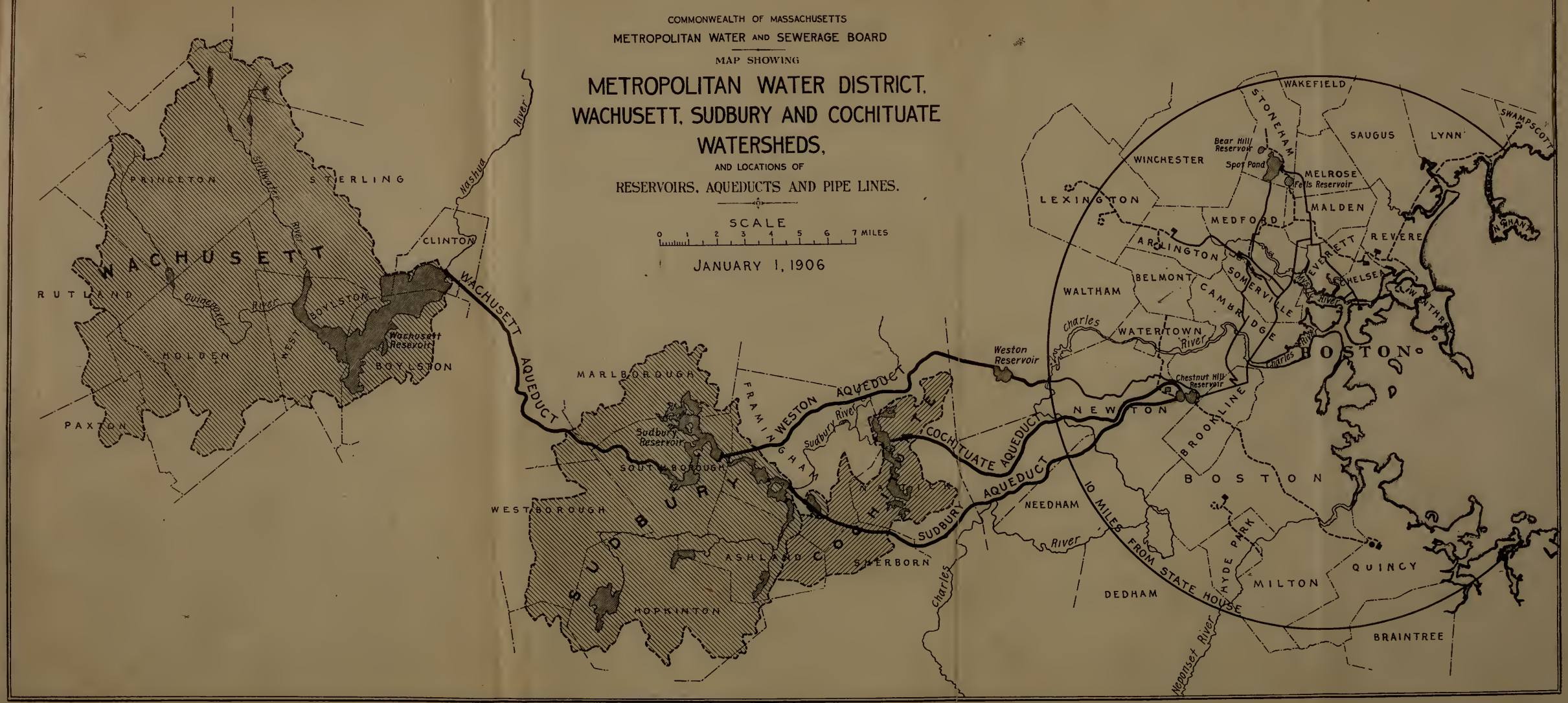
GRADE 1 2500



Main Sudbury Aqueduct

GRADE 1: 5280


415
25.75
20'
22.516
R=90.7'
395
385
28.644
R=248.0
115'
350
47.071
R=789.8'
205'
Bottom of Reservoir 300
81.49
301 Earth Surface
Bottom at Intake Pipes 283
STONE MASONRY
R=355.3
261.35
114.95
1:1
1:1
210
12'
Ledge
about 185'
WACHUSETT DAM
EARTH DAM
Earth Filling at back of Overfall
abt 36'
STONE MASONRY COREWALL
8'
STONE MASONRY OVERFALL
18'
Timber Foundation
DAM Nº 3
266.0
253.0
2:1 Paved
4'
3'
3'
8.05'
259.0
2:1
244.0
2½:1
Paved 2:1
20'
1:2
22.99
abt 73'
CONCRETE COREWALL
STONE MASONRY OVERFALL
R=100'
EARTH DAM
abt 53'
201.0
R=41.06'
9'
Ledge
SUDBURY DAM
20' 0' 20' 40 60 80


COMMONWEALTH OF MASSACHUSETTS
METROPOLITAN WATER AND SEWERAGE BOARD
MAP SHOWING
METROPOLITAN WATER DISTRICT,
WACHUSETT, SUDBURY AND COCHITUATE
WATERSHEDS,
AND LOCATIONS OF
RESERVOIRS, AQUEDUCTS AND PIPE LINES.
SCALE
0 1 2 3 4 5 6 7 MILES
JANUARY 1, 1906
WACHUSETT
PRINCETON
STERLING
RUTLAND
HOLDEN
PAXTON
BOYLSTON
CLINTON
Stillwater River
Quinsigamond River
West River
Nashua River
Wachusett Reservoir
WACHUSETT AQUEDUCT
MARLBOROUGH
SOUTHBOROUGH
WESTBOROUGH
ASHLAND
HOPKINTON
SHERBORN
SUDBURY
Sudbury Reservoir
Sudbury River
FRAMINGHAM
WESTON AQUEDUCT
Weston Reservoir
COCHITUATE AQUEDUCT
SUDBURY AQUEDUCT
Charles River
WALTHAM
WATERTOWN
NEWTON
BROOKLINE
BOSTON
Chestnut Hill Reservoir
Bear Hill Reservoir
Spot Pond
Fells Reservoir
WINCHESTER
STONEHAM
WAKEFIELD
SAUGUS
LYNN
SWAMPSCOTT
MELROSE
MALDEN
LEXINGTON
MEDFORD
ARLINGTON
BELMONT
CAMBRIDGE
SOMERVILLE
EVERETT
CHELSEA
REVERE
WINTHROP
NEEDHAM
DEDHAM
HYDE PARK
MILTON
QUINCY
BRAINTREE
Neponset River
10 MILES FROM STATE HOUSE

Swift rivers with an estimated daily capacity of 271,000,000 gallons, which can be diverted into the Wachusett Reservoir by the construction of tunnels having an aggregate length of about 28 miles.

Upon the Swift River, there is a very favorable location for the construction of a storage reservoir, and a reservoir covering 36.9 square miles with a capacity of over 400,000,000,000 gallons can be made by two dams respectively 2,470 feet long and 144 feet high, above the river, and 2,065 feet long and 114 feet high.

The Assabet, Ware and Swift supplies, with the works already constructed, will provide a safe daily supply of 472,000,000 gallons, while further to the west are the Westfield and Deerfield rivers, capable of furnishing 500,000,000 gallons per day in addition, if required, in the distant future.